NC STATE UNIVERSITY

Hsiao Lab
Re-imagining Interfaces

IFPRI
International Fine Particle Research Institute

Accelerated acoustic prediction of aging and failure

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Wet Systems (Project Review #3, 2026)

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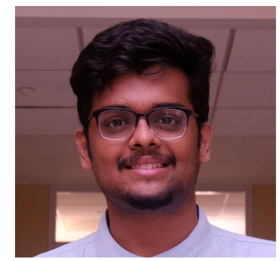

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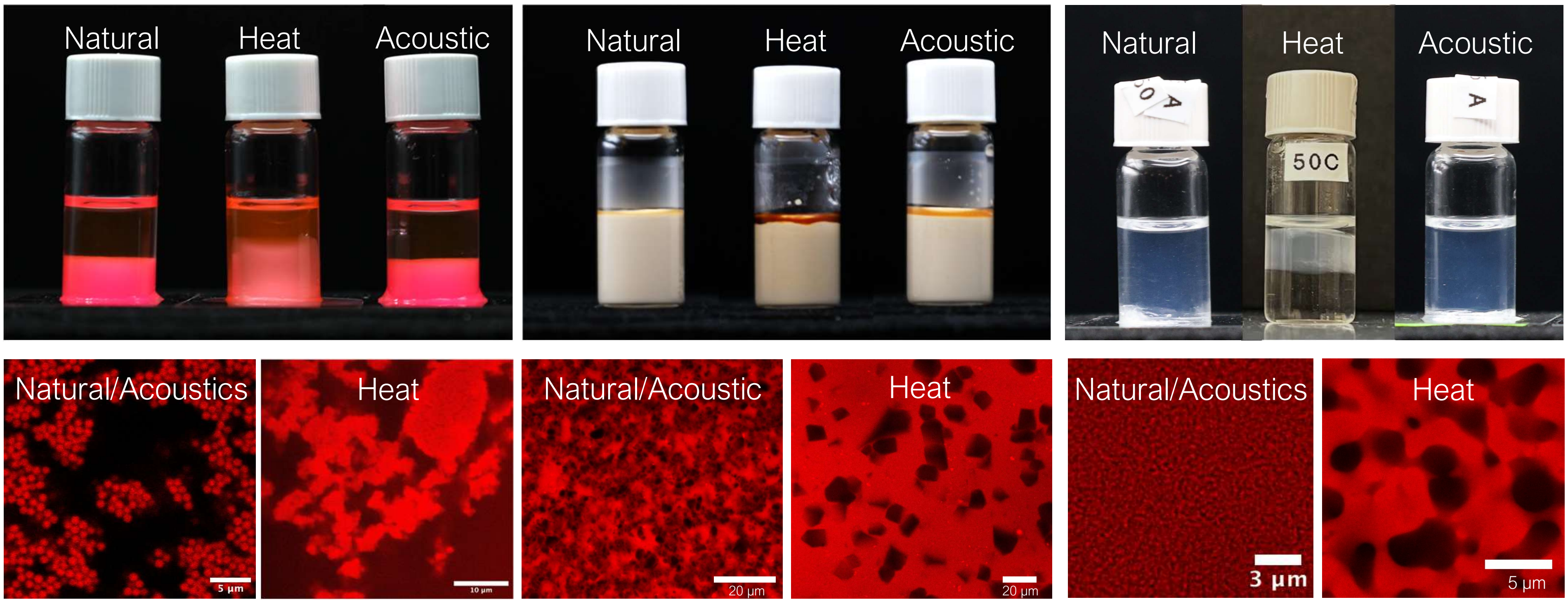
Acoustics accelerate natural aging of wet systems

Colloidal particle dispersions **Commercial suspension concentrates** **Oil/water nanoemulsions**



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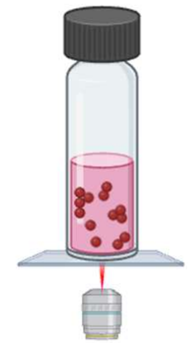
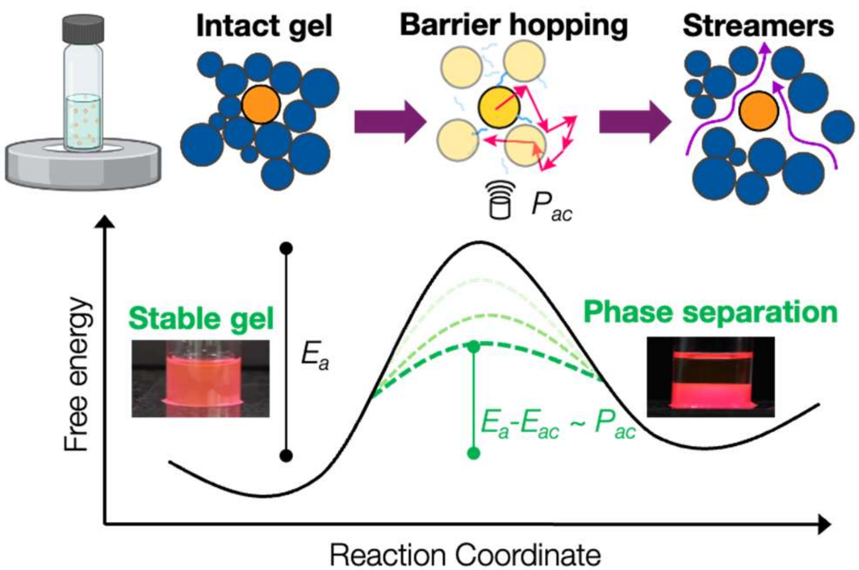
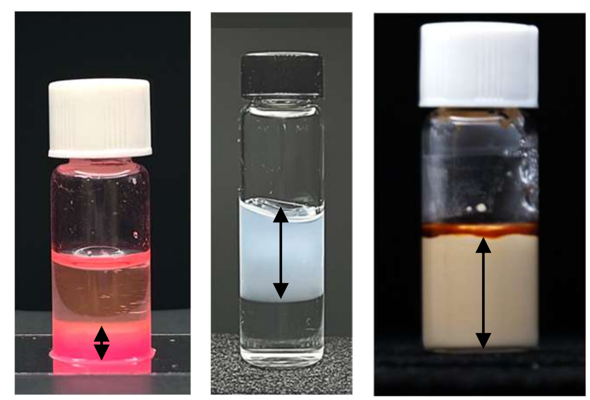
Acoustics as an alternative aging method

Mechanism: Acceleration dominated by acoustic streaming effects

- Acoustic power range: 0.1 - 300 mW (high end)
- Acoustic pressure range: 1 - 30 kPa
- Minimal attenuation from viscous or interfacial losses
- Within the 0.1 mW range, phase separation acceleration factors ~ 5x

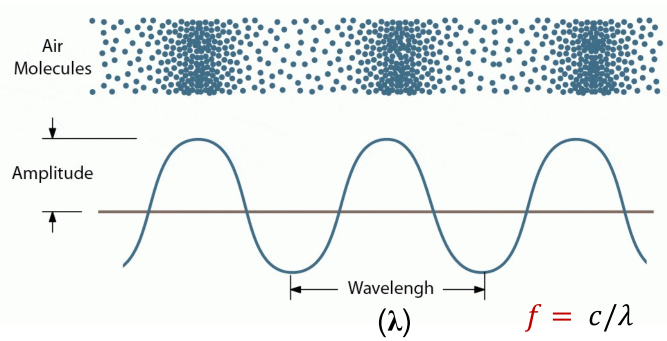






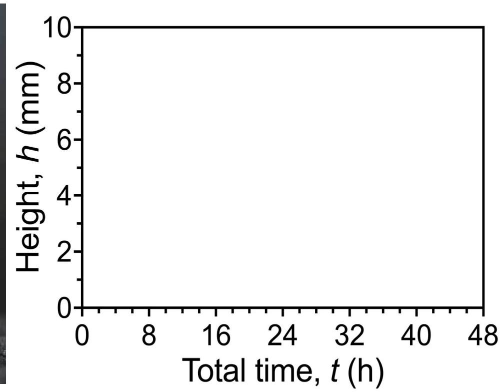
Track microstructure and phase separation

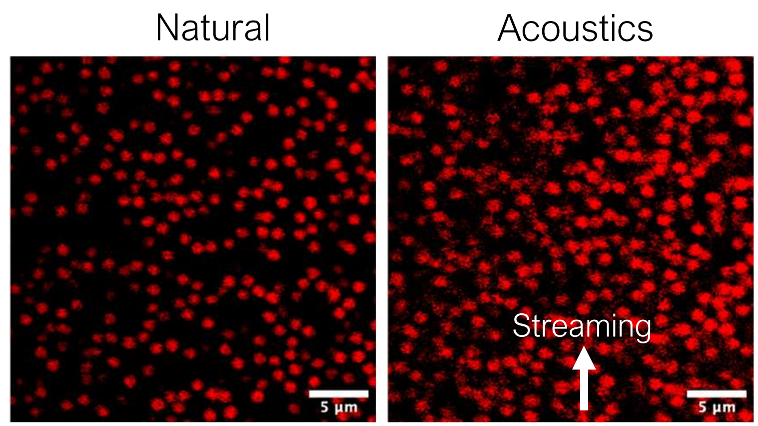
Acoustics as an alternative aging method



Acoustic power range: 0.1 - 300 mW
Acoustic pressure range: 1 - 30 kPa

	PMMA gels	Nanoemulsions
Attenuation/scattering/cavitation	-	-
Acoustic transmittance	0.7	0.8
Radiation pressure potential	0.05 kT	10^{-6} kT
RP velocity (μm/s)	10^{-7}	10^{-10}
Streaming velocity (μm/s)	2.0	1.3
Peclet number (particle)	5.6	0.01
Mechanism	**Streaming**	**Brownian/interfacial**

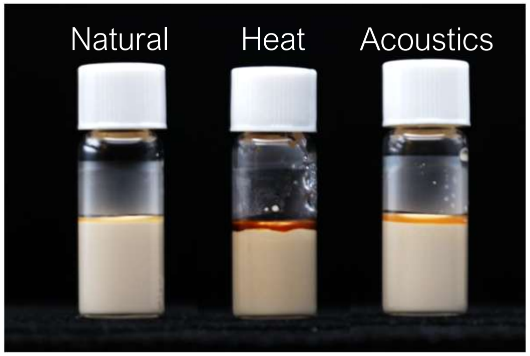


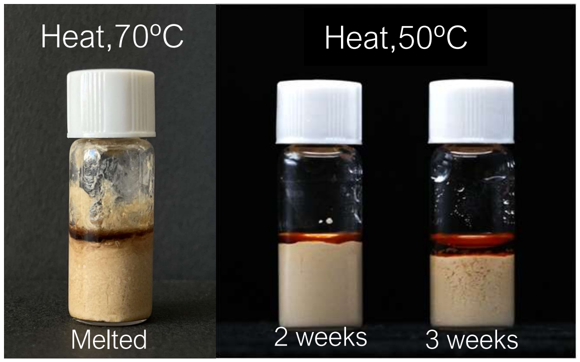


Acoustic vs. heat treatment of commercial suspensions

Heating is fast, but causes unnatural changes in formulations

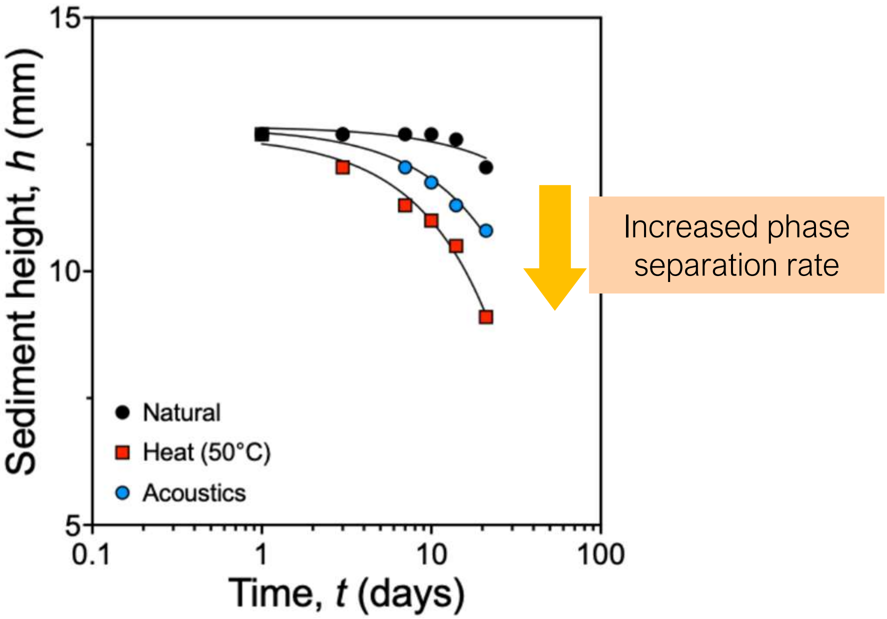
IFPRI suspension concentrates





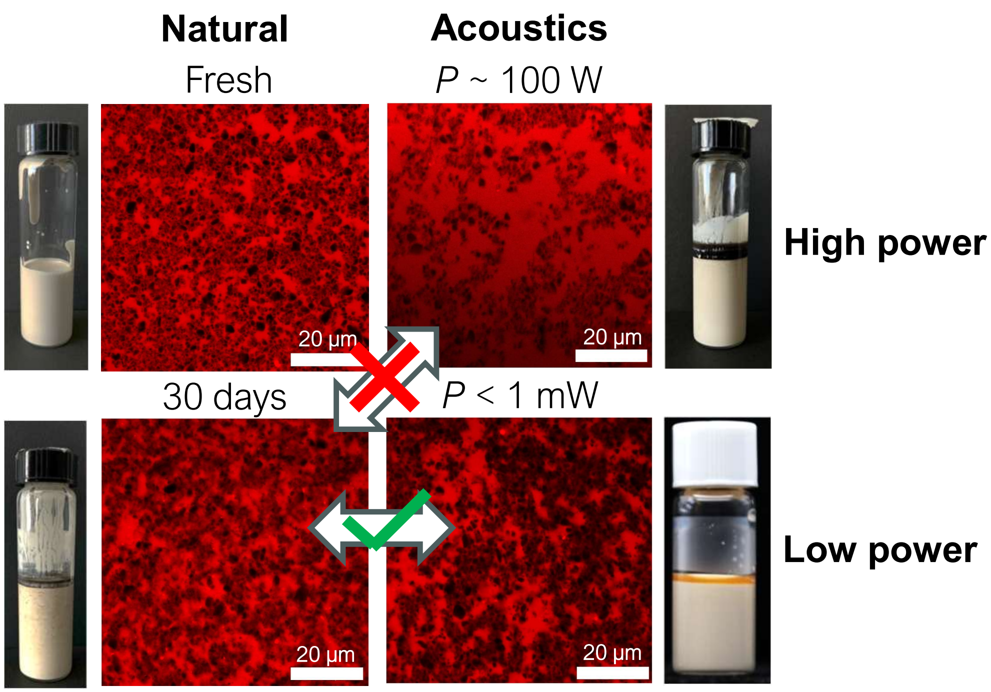
Degradation temp = 54ºC

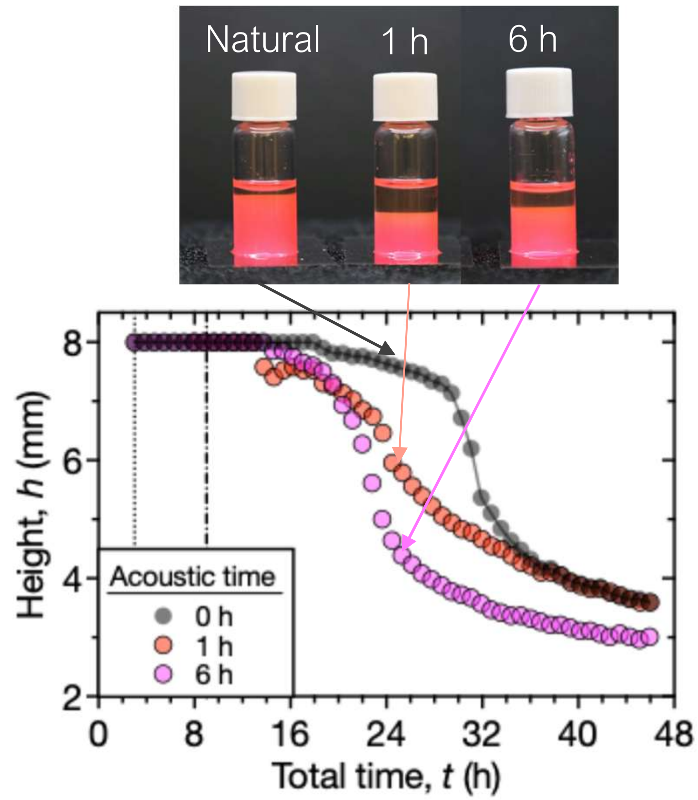
Acceleration factor from heating: 10-15x
Acceleration factor from acoustics: 5-6x



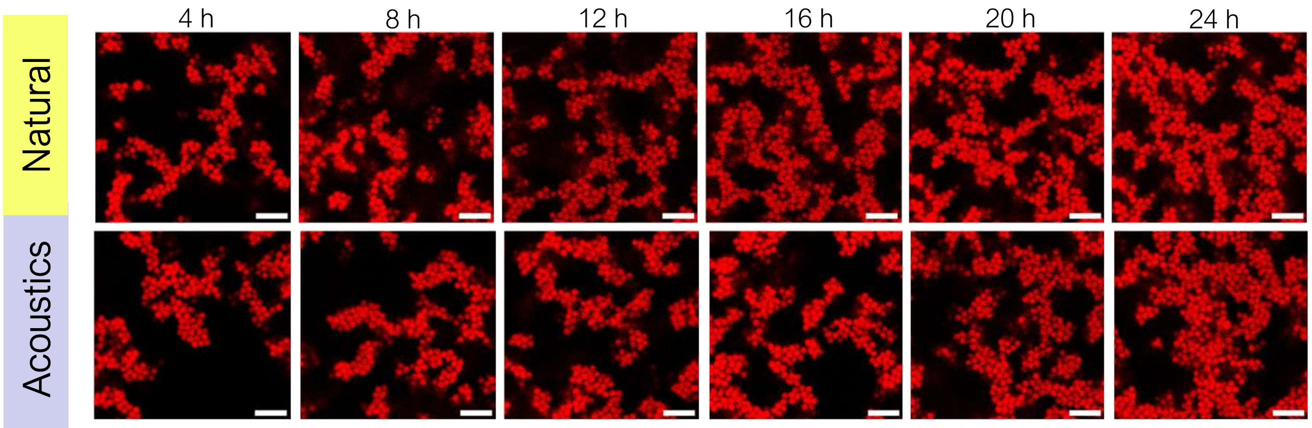
Why not simply increase the acoustic exposure?

- Possible, but overly high power leads to local heating and deterioration of samples
- Nonlinear effect (i.e. more power/exposure does not mean faster)
- This is seen in both PMMA gels and oil/water nanoemulsions

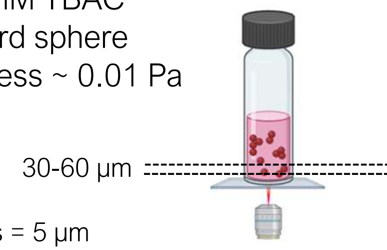




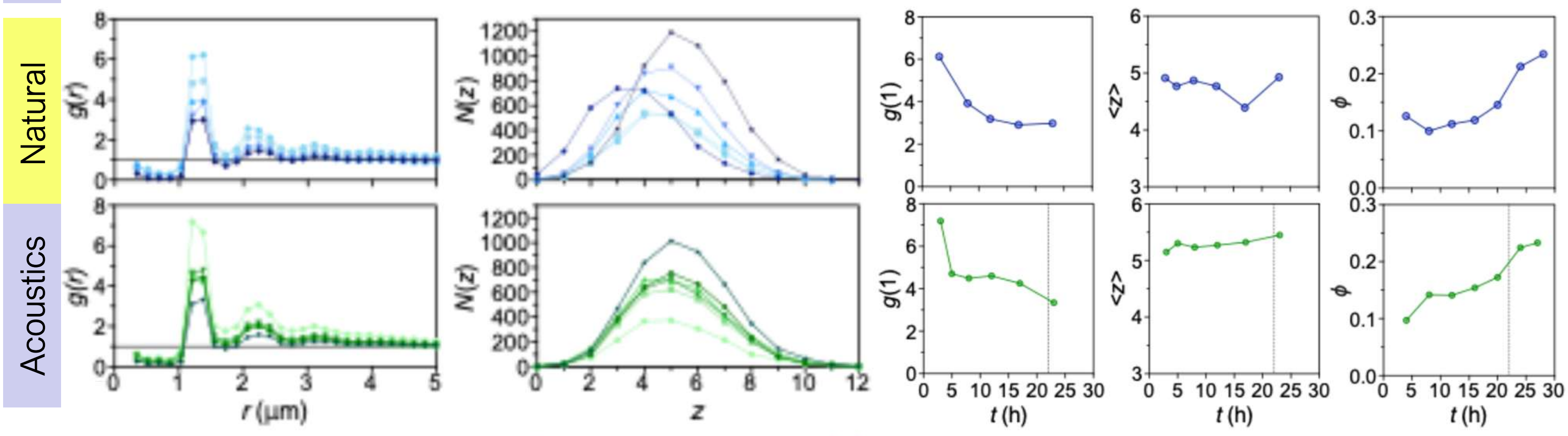
Structural analysis on colloidal gels



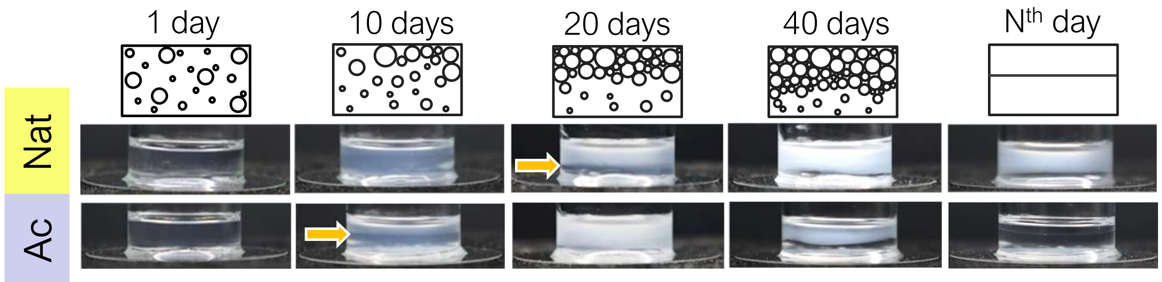
<u>PHSA-PMMA colloidal gels</u>
$2a$ = 1 µm ± 3%
Solvent: 66/34 v/v CHB/decalin
Depletant: Polystyrene (M_w = 10^6 Da)
c/c^* ~ 1, ϕ = 0.10
Salt: 4 mM TBAC
Near-hard sphere
Yield stress ~ 0.01 Pa



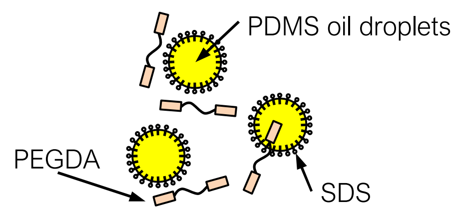
Scale bars = 5 µm

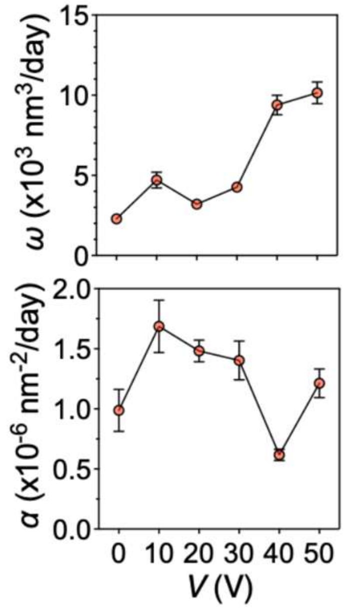


Effect of acoustic power and frequency on emulsions

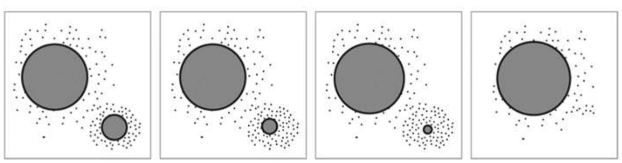


PDMS oil/water nanoemulsions
2a ~ 40 nm ± 30%
Dispersed phase: PDMS (5 cSt), ϕ = 0.20
Continuous phase: De-ionized water
Surfactant: 200 mM sodium dodecyl sulfate
Co-surfactant: 33 vol% PEGDA (M_w = 700Da)
Yield stress ~ 1 Pa





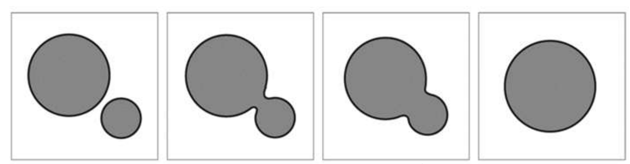
Ostwald ripening



$\langle r_H \rangle \sim t^{\frac{1}{3}}$

Self-similar PSD

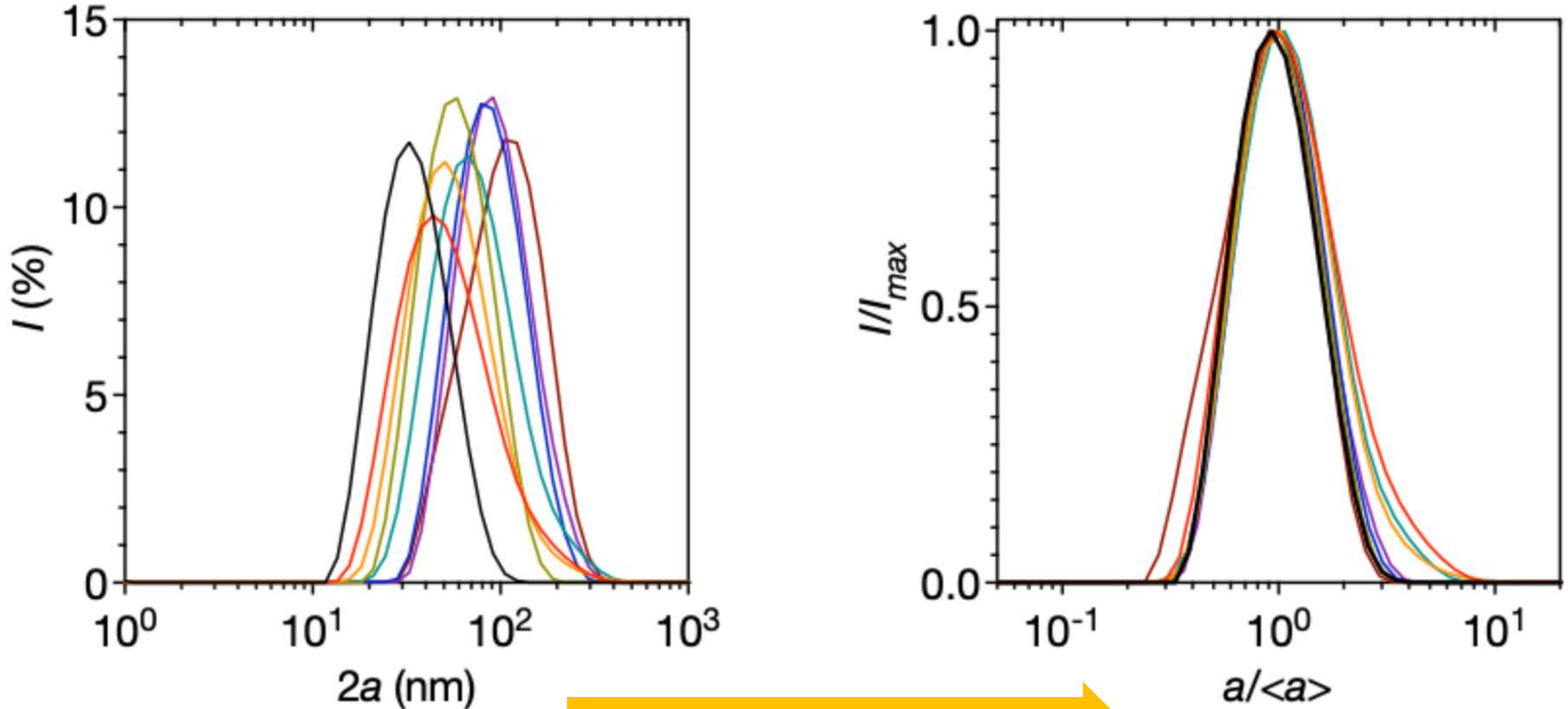
Coalescence



$\langle r_H \rangle \sim t, t^{\frac{1}{2}}, t^{\frac{1}{3}}$

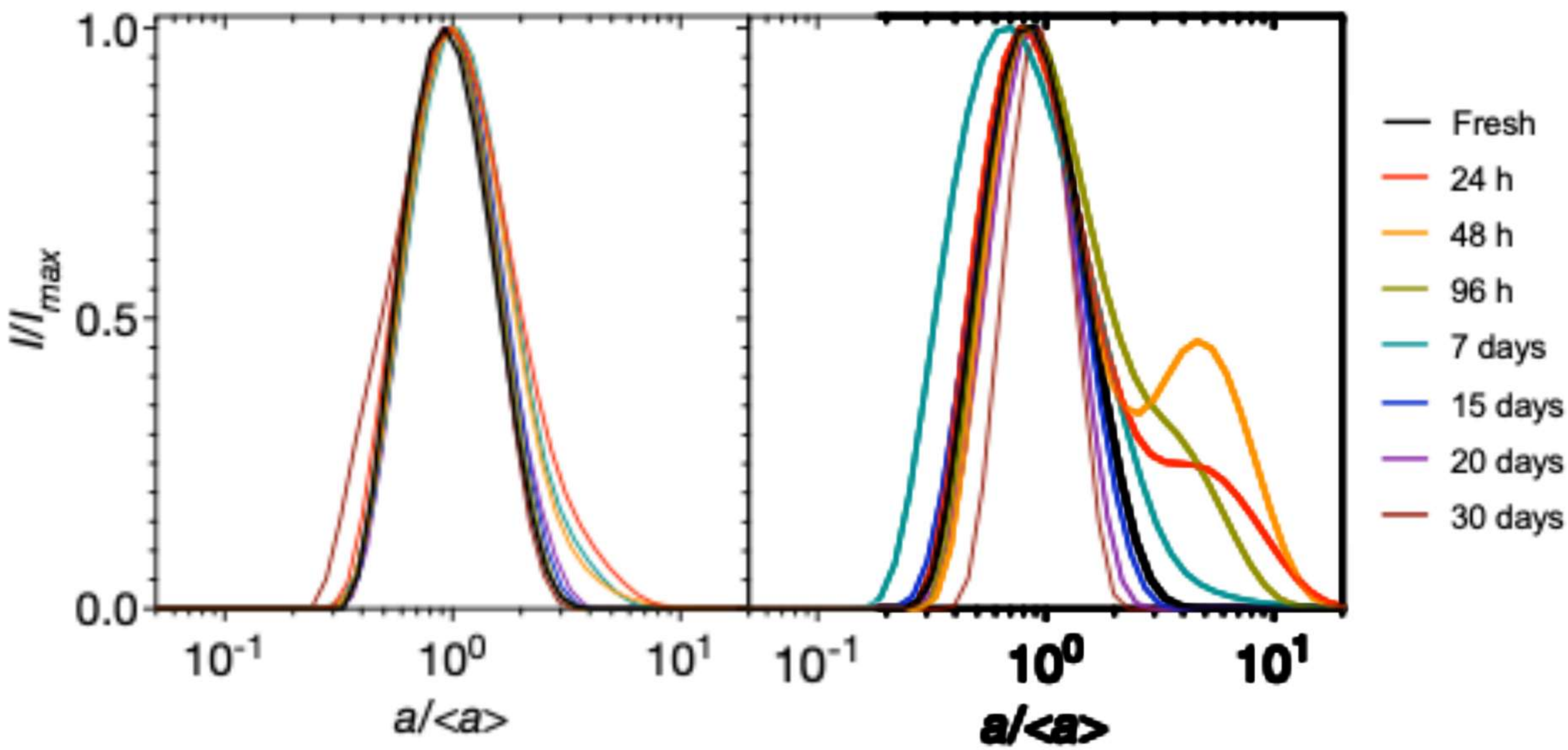
Broadening PSD

Particle size distributions of coarsening emulsions



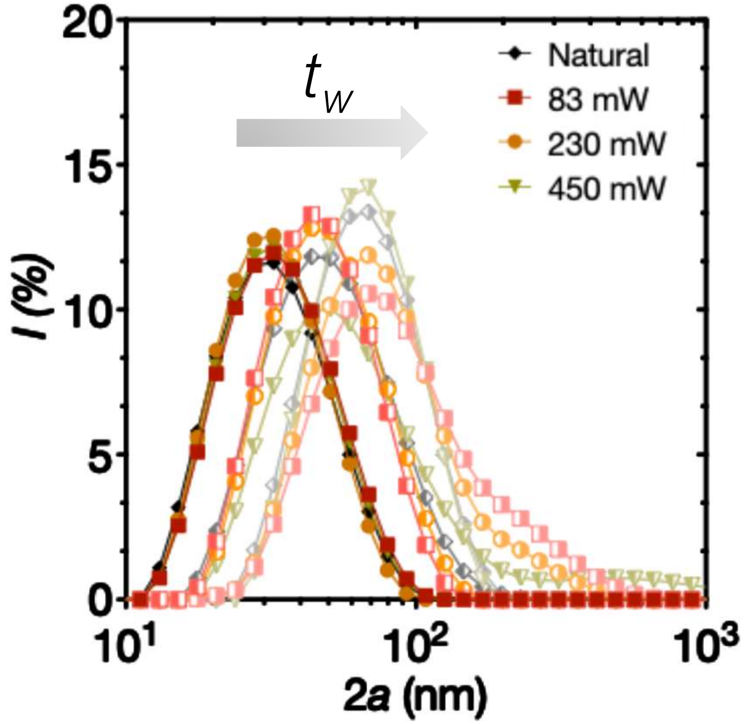
Log-normal fitting
Changes in distribution width

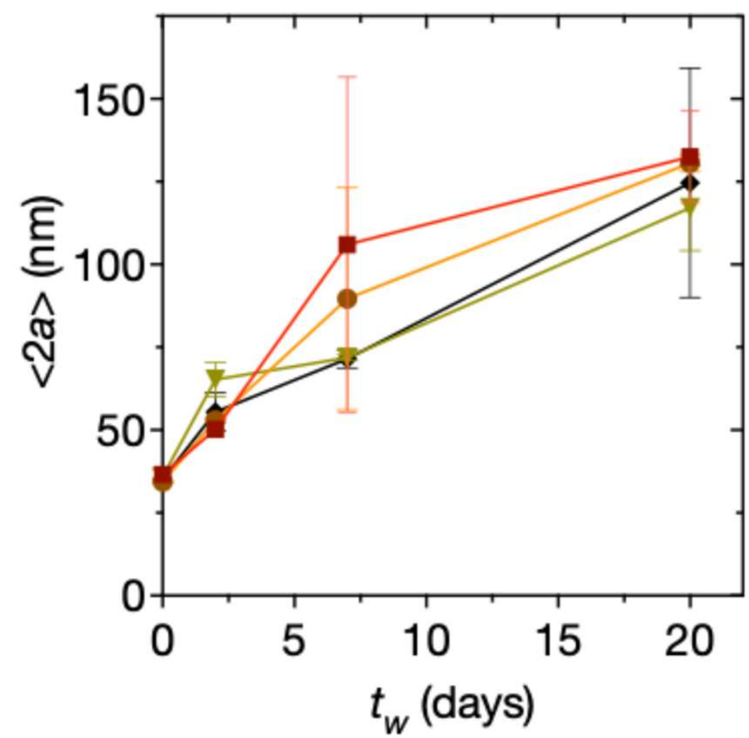
Effect of acoustics on particle size distribution



Bimodal distribution develops in acoustically aged samples
Generates onset of early-stage coalescence

Effect of acoustic power on nanoemulsions

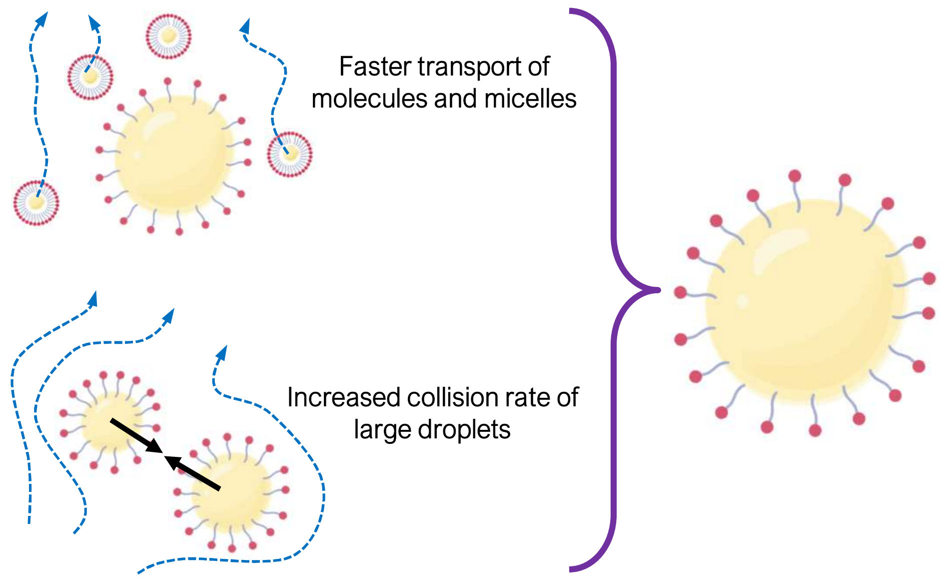




Increases coalescence rates with increasing *P*
Little effect on the average diameter

Mechanism for accelerated coarsening in nanoemulsions

	Nanoemulsions
Attenuation/scattering/cavitation	-
Acoustic transmittance	0.8
Radiation pressure potential	10^{-6} kT
RP velocity (μm/s)	10^{-10}
Streaming velocity (μm/s)	1.3
Peclet number (particle)	0.01
Mechanism	**Brownian/interfacial**



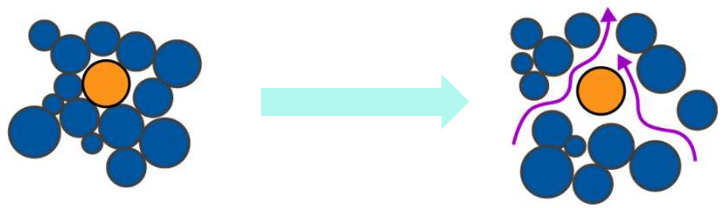
Streaming-induced Ostwald ripening/Marangoni flows

- Enhanced mass transport of barely soluble PDMS oil to droplets
- Increased surfactant gradient around individual droplets
- Negligible droplet or micelle deformation (Laplace pressures and timescales)

Summary and plans

Acoustics increase convective mass transport in wet systems

- Works very well in ~μm range
- Captures non-equilibrium processes such as vibrations during pumping/transportation
- Promising at enhancing transport-limited processes such as mesoscale fluid drainage
- Offers direct microscop ic observability
- **Comparisons to accelerated syneresis could be fruitful (Del Gado project)**



Plans for Y4:

- *In situ* visualization of flow fields with acoustics
- Testing effect on syneretic systems (solvent separation from gel network)
- Systematic evaluation of acceleration factor in colloidal dispersions

Very special thanks to Brian Levy-Polis (FMC), Vicky Cheng (FMC), Kelly Krzysik (Dow), other members... and Eric Furst for asking if we figured it out yet

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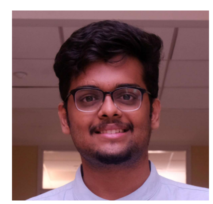

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